Abundance and Distribution of Porpoise and Other Marine Mammals of the Inside Waters of Washington and British Columbia

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Introduction

The inside marine waters of Washington and British Columbia are highly productive, supporting a rich diversity of habitats and animal life, including nine species of commonly occurring marine mammals (Osborne et al. 1988; Calambokidis and Baird 1994). Three of the marine mammals, harbor seals (*Phoca vitulina richardsi*), harbor porpoise (*Phocoena phocoena*) and to a lesser extent, Dall's porpoise (*Phocoenoides dalli*), are vulnerable to entanglement in gillnets (Stacey et al. 1990, 1997; Gearin et al. 1995; Barlow et al. 1995a; Pierce et al. 1996).

The National Marine Fisheries Service (NMFS) is responsible for reducing human-caused marine mammal mortality below levels deemed to be significant based on abundance estimates within U.S. waters (Barlow 1995b). However, the marine mammals of this region undoubtedly use both U.S. and Canadian inside waters and are affected by national, provincial and state regulations. Therefore, the National Marine Fisheries Service (NMFS), National Marine Mammal Laboratory, Washington, in cooperation with the Department of Fisheries and Oceans, British Columbia, was interested in estimating abundance for these three species in this entire inside water region.

For the inside waters of Washington and British Columbia, data on harbor porpoise and Dall's porpoise is insufficient to determine the effect of incidental takes on their population size. The harbor porpoise abundance estimates are either outdated (Calambokidis et al. 1992) or do not include most of these inside waters (Flaherty and Stark 1982; Osmek et al. 1995). Dall's porpoise abundance estimates are lacking except for one area in Puget Sound (Miller 1989). Recent estimates of harbor seal abundance exist for U.S. (Jeffries et al. 1997) and most of British Columbia inside waters (Olesiuk et al. 1990; Olesiuk In prep.).

We report the preliminary results of aerial surveys for marine mammals that cover the inside waters of Washington and British Columbia (see Calambokidis et al. 1997). Additional analyses of these data are still underway and will be compared to a re-analysis of the 1991 survey data (Calambokidis et al. 1992) to determine possible trends in harbor porpoise and Dall's porpoise abundance. The objectives of this study were to estimate abundance of harbor porpoise and Dall's porpoise and to examine the geographic distribution of these species plus harbor seals. Data on harbor seal and porpoise distribution is used to evaluate whether certain areas of high sighting rates might be identified as locations to be avoided by fisheries known to incidentally take these species in their gill nets (see Pierce et al. 1996).

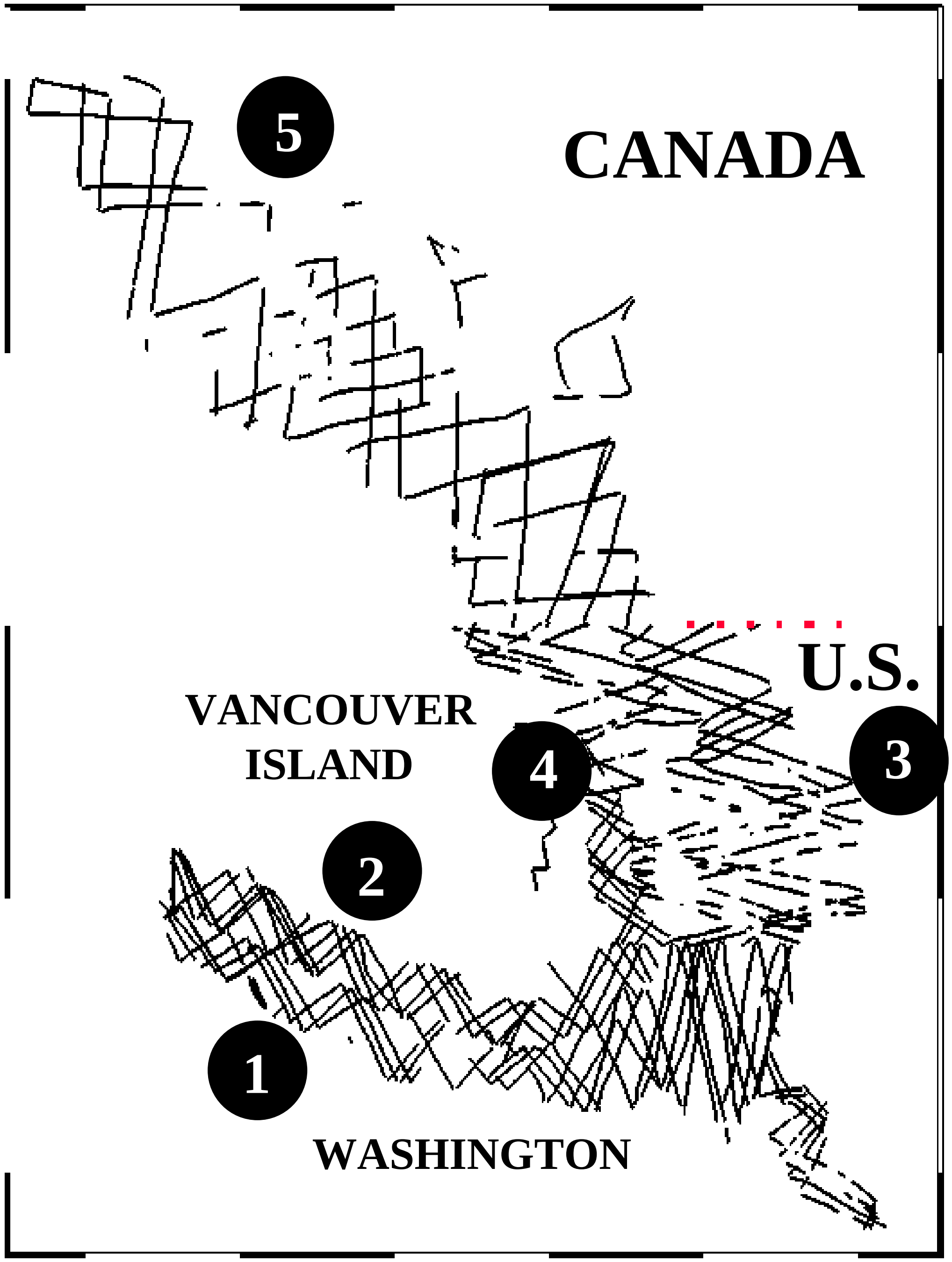

Figure 1. Study area and on-effort survey transects (bold lines). The five regions, (1) U.S. Strait of Juan de Fuca, (2) Canadian Strait of Juan de Fuca, (3) U.S. San Juan Islands, including Admiralty Inlet, (4) Canadian Gulf Islands, and (5) the Strait of Georgia (49°N to 50°), were flown under acceptable visibility conditions of Beaufort level ≤ 2 and cloud cover ≤ 25%.

Methods

Study Area

The 1996 study area included the inside waters of Washington and British Columbia within latitudes 47°53' N to 50° N and the western entrance of the Strait of Juan de Fuca (124.44° W) (Figure 1). This western edge of the study area is the line extending from Tatoosh Island, WA to Bonilla Point, BC, a boundary used by NMFS to define and manage two harbor porpoise stocks (Osmek et al. 1996). The study area was divided into five separate regions based on water bodies and the international border: 1) U.S. Strait of Juan de Fuca (2,971 km^2), 2) Canadian Strait of Juan de Fuca (2,137 km^2), 3) U.S. San Juan Islands, including Admiralty Inlet (1,531 km^2), 4) Canadian Gulf Islands (1,350 km^2), and 5) the Strait of Georgia (49° N to 50° N; 6,370 km^2). Surveys of Hood Canal and Puget Sound proper (south and east of Whidbey Island) were not flown because harbor porpoises densities were known to be extremely low (Calambokidis et al. 1992; Osmek et al. 1995).

Survey Design and Data Acquisition

From 7–22 August 1996, a total of 6,263 km of aerial line transect surveys were conducted following a saw-tooth design (Cooke 1985) from a high-wing (Partenavia P-68) twin engine aircraft flying at an altitude of 183 m (600 ft) and a speed of 167 km/hr (90 kts). Every minute, and whenever a sighting occurred, the aircraft position was automatically recorded on a laptop computer connected to a GPS. Beaufort wind scale (sea state) and percent cloud cover was entered at the beginning of each transect and when visibility conditions changed. Five unique replicate survey lines were flown in all areas except the Strait of Georgia, where three replicates were flown.

Sighting data were acquired by three observers, located at each side bubble window and the belly window and was entered in to the computer by the recorder located in the copilot's position. Sighting data included species, group size, presence of young animals, and clinometer angle measured from the aircraft to the group as it passed abeam of the aircraft. This measurement was used to calculate the distance from the trackline and to more accurately estimate the position for each sighting. Most groups were sighted within 400 m of the trackline.

Water depth data were determined for all sightings and one-minute aircraft positions using nautical charts published by the U.S. National Oceanic and Atmospheric Administration and Canadian Hydrographic Service, Department of Fisheries and Oceans. Chart scale ranged from 1:40,000 to 1:80,000 in U.S. waters and was 1:80,000 in Canadian waters. Depths were interpolated to the nearest meter or fathom. Due to the large sample sizes of harbor seals and aircraft positions, every fourth harbor seal sighting and every other aircraft position were measured and subsequently used to calculate mean depth. The one-minute aircraft positions were considered an unbiased estimator of effort because the recorded location was independent of the waypoint positions used to define the flight path.

Geographic Distribution

Geographic cells, measuring 10 minutes latitude (18.5 km) by 15 minutes longitude (19 km) (352 km^2), were defined throughout the study area and sighting rates were computed (groups/100 km). To ensure a sufficient number of sightings per cell, we only used a minimum of 40 km of aerial effort for the porpoise cells and 20 km for harbor seal cells.

A 2-way ANOVA was used to analyze sighting rates (animals/km) differences by depth and region. Samples consisted of pooled transect segments from each replicate survey in a region that were conducted within a specific depth class of each region under acceptable sighting (weather) conditions. Only samples with a minimum of two "one-minute" effort positions (representing an average of at least 5 km) were used in the depth analysis to reduce variation from minimally sampled strata. All statistical tests were conducted with a 0.05 significance level.

Density and Abundance Estimation

We statistically tested differences in the number of animals seen per kilometer of survey effort among regions, Beaufort sea state, percent cloud and year using an analysis of covariance (ANCOVA) procedure similar to that employed by Forney et al. (1991). Samples consisted of pooled transect segments from each replicate survey in a region that were conducted under acceptable weather conditions under similar visibility conditions (Figure 1). The results of the analysis indicated that only data collected under the best conditions of sea state (Beaufort ≤2) and cloud cover (≤25%) should be used in order to reduce bias. A total of 4493 km of total on-effort survey trackline was retained and used to determine abundance.

Table 1. Survey regions, effort and preliminary sighting rates during 1996.

	Area	Effort	Harbor porpoise			Dall's Porpoise		
Region	(km^2)	(km)	Sightings	Animals	Sight rate	Sightings	Animals	Sight rate
U.S. Strait of Juan de Fuca	2,971	1,365	90	127	0.066	29	49	0.021
U.S. San Juan Islands	2,137	752	58	83	0.077	11	15	0.015
Canadian Strait of Juan de Fuca	1,531	728	60	86	0.082	11	20	0.015
Canadian Gulf Islands	1,350	546	31	44	0.057	13	28	0.024
Strait of Georgia	6,370	1,102	20	23	0.018	0	0	0.000
Total	14,359	4,493	259	363	0.058	64	112	0.014

Density and abundance estimates were calculated with the computer program DISTANCE (Laake et al. 1993) and the methods described in Burnham et al. (1980) and Buckland et al. (1993). DISTANCE was used to select the best model for the probability density function fit to the perpendicular distances, calculate f(0) and its variance, and to test for relationships between group size and distance from the transect line. Abundance was calculated as:

$$N_r = \frac{n_r * E(S_r) * f(0) * g(0) * A_r}{2L_r}$$

where $\mathbf{N_r}$ denotes estimated abundance in a region, **r** = one of five regions, $\mathbf{n_r}$ denotes sightings in a region, $\mathbf{E(S_r)}$ = group size for that region, **f(0)** = the probability density function at distance zero, **g(0)** = the probability that an animal is detected on the trackline, and $\mathbf{L_r}$ is the distance surveyed in region, and A_r is the area of the region. A g(0) of 0.292, (CV=36.6%) was used based on calibration surveys conducted in the San Juan Islands in 1992 (Laake et al. 1997) which used the same aircraft and survey procedures employed in this study.

Estimates of variation for the regional abundance estimates were defined using:

$$cv(N_r) = \left[\left(cv(n_r)\right)^2 + \left(cv(E(S_r))\right)^2 + \left(cv(f(0))\right)^2 + \left(cv(g(0))\right)^2 \right]^{\frac{1}{2}}$$

The variance for $\mathbf{n_r}$ was calculated based on the replicate surveys conducted in each area (Buckland et al. 1993, p. 90). Pooled estimates of abundance were calculated as the sum of the regional estimates.

Results

A total of 1,505 sightings of 3,340 animals from nine marine mammal species were sighted during the on-effort portions of the two-week survey (Figure 2). The three most common species were harbor seals, harbor porpoise, and Dall's porpoise, accounting for 71%, 22% and 6% of all sightings, respectively. Other species sighted under acceptable visibility conditions were killer whales (n=8) (*Orcinus orca*), gray whales (n=3) (*Eschrichtius robustus*), minke whales (n=2) (*Balaenoptera acutorostrata*), Steller sea lions (n=3) (*Eumetopias jubatus*), California sea lions (n=1) (*Zalophus californianus*), and sea otters (n=3) (*Enhydra lutris*) (Figure 3). No marine mammals other than harbor seals and harbor porpoise were sighted in the Strait of Georgia.

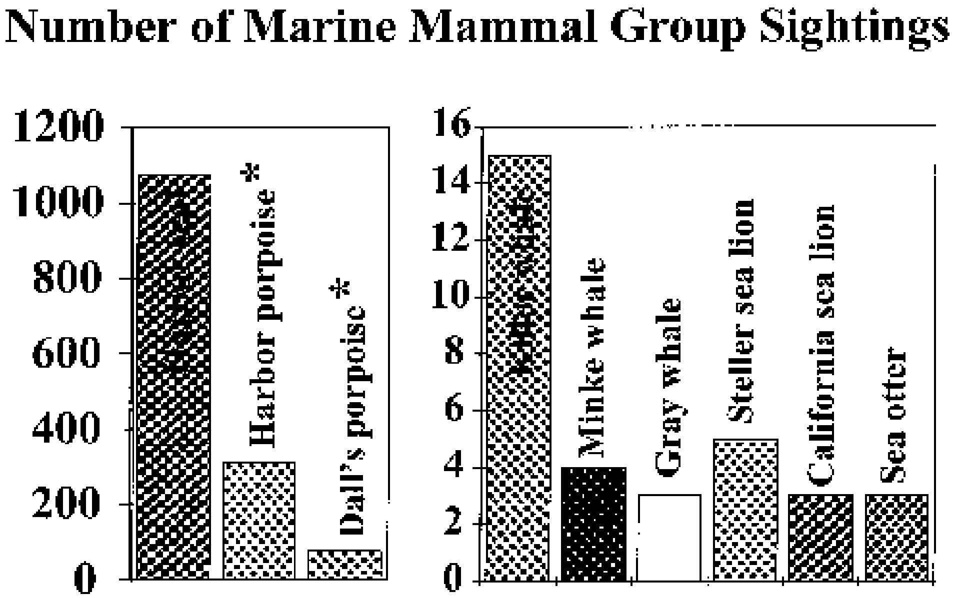

Figure 2. A total of 1,505 sightings of 3,340 animals from nine marine mammal species were sighted during the on-effort portions of the two-week survey. The tree most common species were harbor seals, harbor porpoise, and Dall's porpoise, accounting for 71%, 22%, and 6% of all sightings, respectively. Abundance estimates were calculated for the two porpoise species(*).

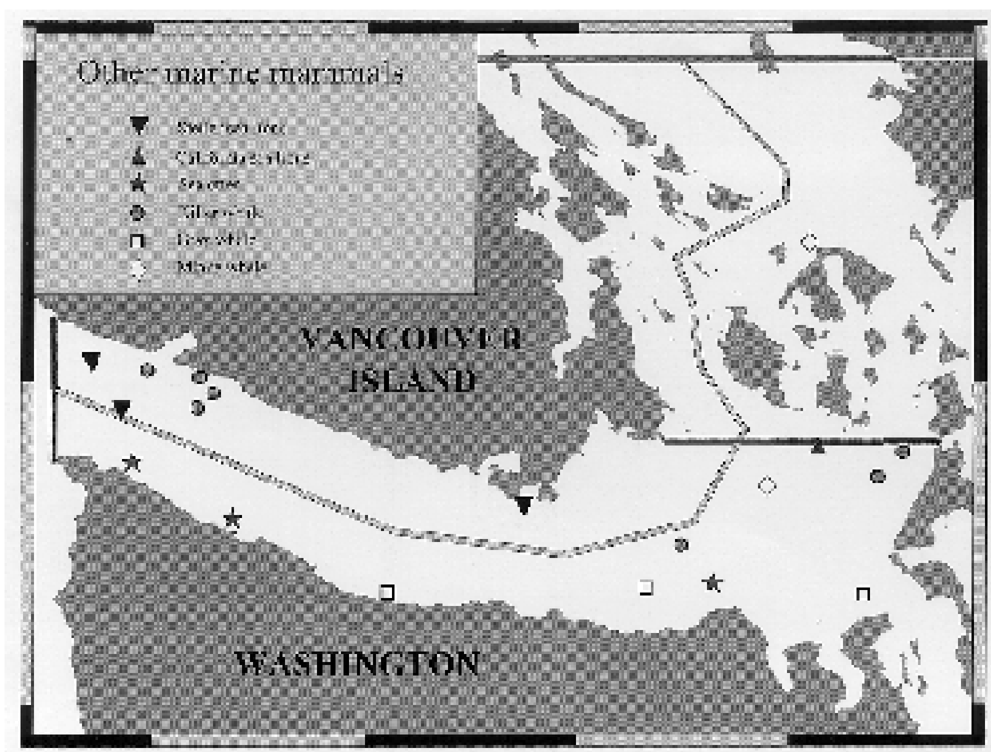

Figure 3. Locations of the other marine mammals seen during the 1996 surveys of the inside waters of Washington and British Columbia, Canada.

Harbor Seals

Sightings and Geographic Distribution

Harbor seal sightings were common and occurred throughout the study area in the narrow passages as well as in open water (Figure 4). A total of 862 groups (974 seals, including 20 pups) were observed at sea, while 26 groups (1,159 animals) were hauled out at various land sites.

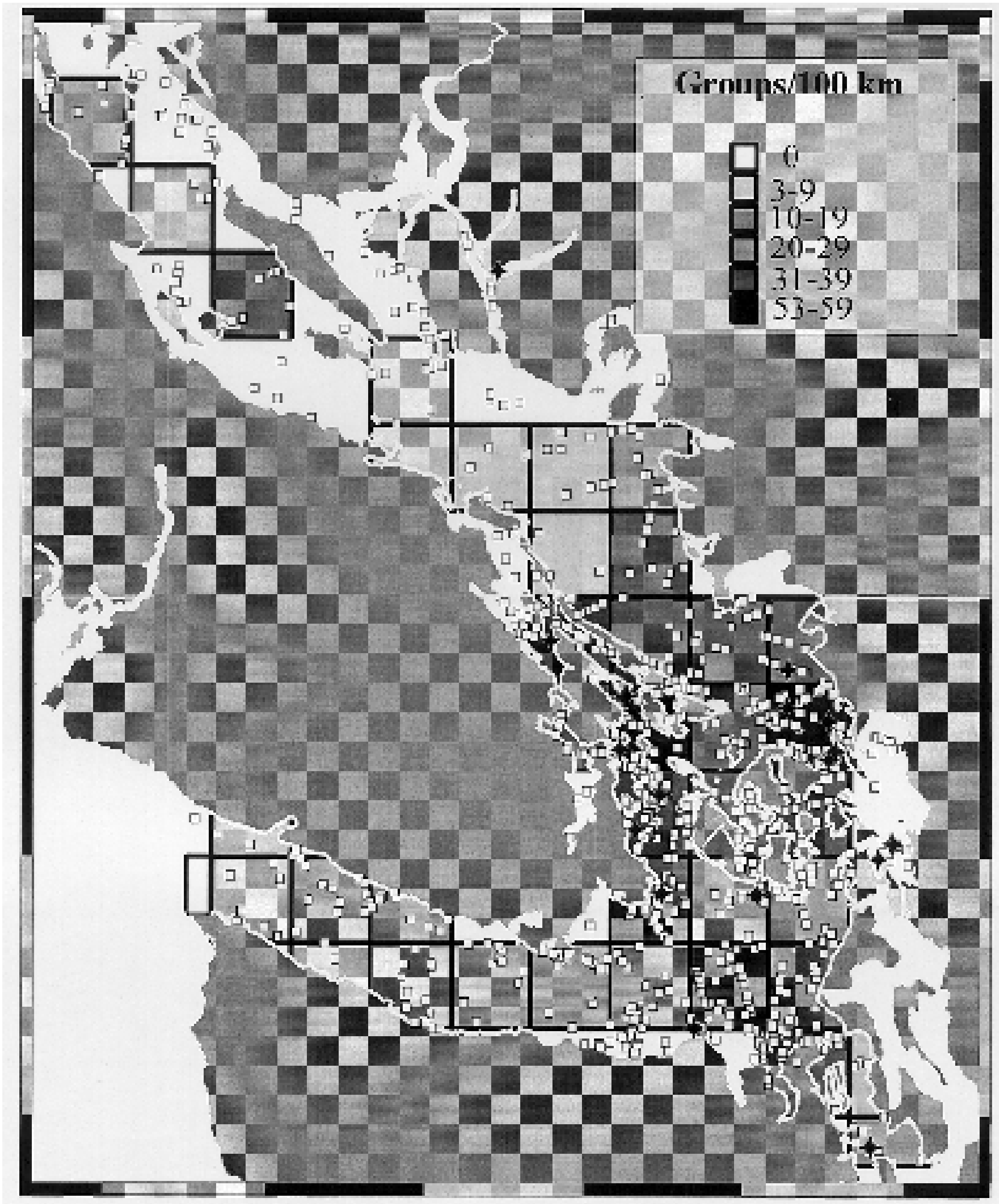

Figure 4. On-effort sightings of harbor seals and haul sites made under acceptable visibility conditions. Also shown are effort-corrected sighting rates (at sea) of harbor seals for geographic cells (352 km^2). A minimum of 20 km of aerial effort was required for each cell to ensure an adequate number of sightings were available for comparison with other cells.

Harbor seal sighting rates varied significantly by region and depth (2-way ANOVA, P<0.05). Sighting rates were highest in the two island regions of the (29.5–33.7 groups/100 km) and similar in the others (13.1–16.4 groups/100 km). Although harbor seals were sighted most in the shallower waters of each region (Figure 5), this species occurred in all depth classes.

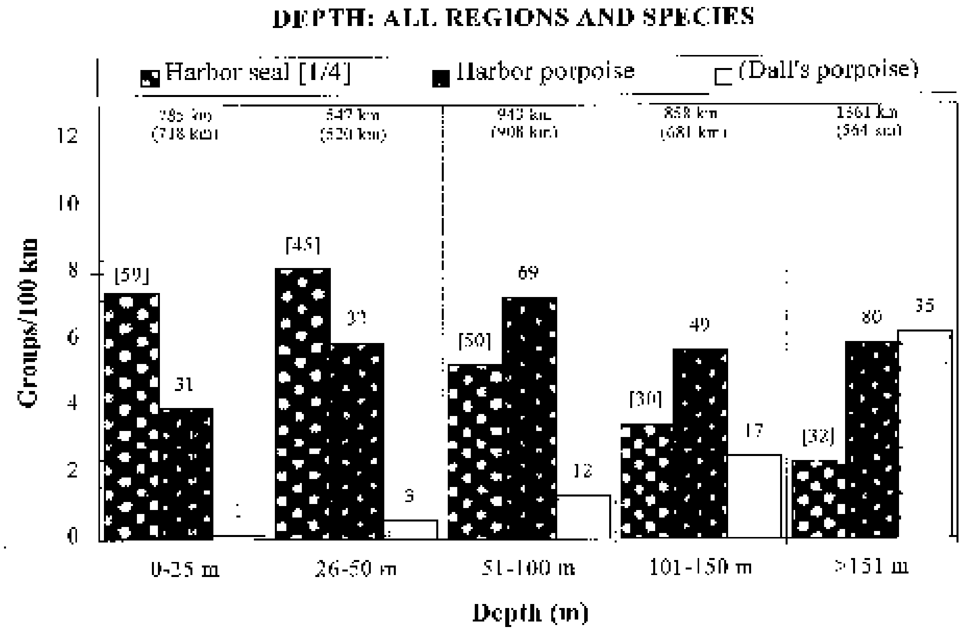

Figure 5. Sighting rate by depth class for harbor seals, harbor porpoise, and Dall's porpoise observed in the study area under acceptable visibility conditions. Seal rates and sightings were four times greater than shown due to data subsampling. Because no Dall's were sighted there, the survey effort for the Strait of Georgia was excluded from the analysis for Dall's porpoise.

Out of a total of 38 geographic cells, 37 contained at least one seal sighting; rates varied greatly from three to 59 groups per 100 km of effort (Figure 4). The highest rates (31–59 groups/km) were found in two clusters of cells encompassing: (1) the northern Gulf Islands, and (2) northeast Orcas Island. The sighting rates adjacent to these cell clusters were also high (21–29 groups/100 km) and comparable to those in the eastern Strait of Juan de Fuca near western Whidbey Island and around Protection and Smith Islands, which are well established haul sites (Huber 1995). The highest rates in the Strait of Georgia (21–29 groups/100 km) were comparable for two cells: (1) between Hornby and Texada Islands, and (2) near the Fraser river mouth and Robert's Bank, an alluvial sand bar that is extensively used for hauling.

Abundance

Density and abundance estimates of harbor seals were not calculated because adequate estimates have already been calculated for this species based on counts of haul-out sites in these waters (see Jeffries et al. 1997; Olesiuk et al. 1980; Olesiuk in press.).

Harbor Porpoise

Sightings and Geographic Distribution

A total of 382 sightings of 549 harbor porpoise were made during the surveys, with 311 of these sightings made on-effort (Figure 6). Group sizes of harbor porpoise ranged from one to three (66% single animals), with the exception of two off-effort sightings of six animals.

Harbor porpoise occurred throughout the study area with few breaks in their geographic distribution. Sighting rates for harbor porpoise were highest in the Canadian Strait and San Juans (8.0–8.1 groups/100 km) and lowest in the Strait of Georgia (1.9 groups/100 km). Sighting rates varied significantly by regions and by the interactive effect of region and depth. When the Strait of Georgia was excluded from the analysis, no significant differences existed between the other four regions. The interactive significance is due to the differences in the depth distribution pattern by region. However, unlike seals, an opposite pattern of increasing sightings with increased depth was apparent in both island regions; no clear pattern was detectable for harbor porpoise in the three other regions alone or all regions combined (Figure 5).

Harbor porpoise sightings occurred in all 19 cells; and rates ranged from one to 21 sightings per 100 km (Figure 6). (The Strait of Georgia was unrepresented for both porpoise species because effort there was mostly less than 40 km per cell). Sighting rates were highest (21 groups/100 km) northwest of Orcas Island and almost as high (15–16 groups/100 km) in the following areas: (1) west of Whidbey Island, (2) off Victoria, British Columbia, and (3) in the central U.S. Strait.

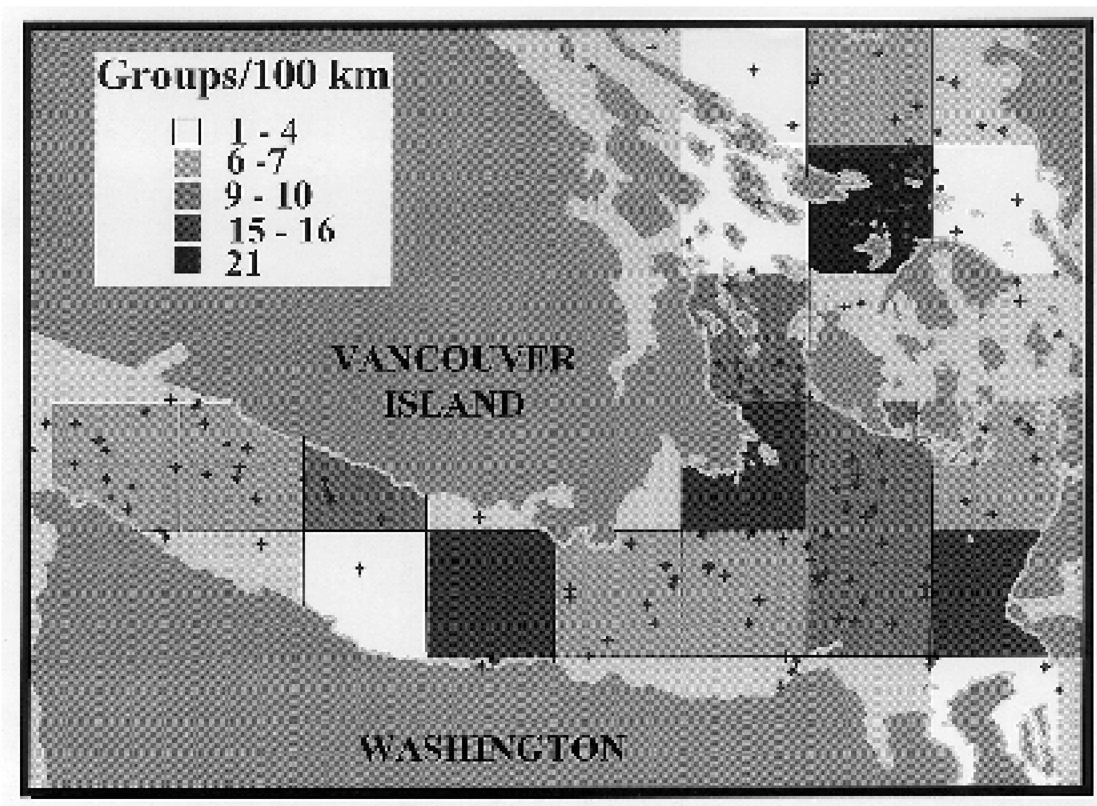

Figure 6. Harbor porpoise sighted while on-effort under acceptable visibility conditions. Effort-corrected sighting rates measured 352 km^2 and contained a minimum of 40 km of aerial effort.

Preliminary Abundance Estimates

Sighting rates showed a steady decrease with distance from the transect line, and a truncation distance of 0.375 km (sightings >64 degrees with 0 = vertical) only eliminated two harbor porpoise sightings. The best model of the sighting distances was the Uniform key with one polynomial adjustment.

The preliminary estimate of harbor porpoise abundance was approximately 6,000, with approximately 50%, 35%, and 15% of the population found in the Strait of Juan de Fuca, San

Juan/Gulf Islands, and the Strait of Georgia, respectively (see Calambokidis et al. 1997 for additional details). This estimate is corrected for the number of animals missed on the transect line (uncorrected estimate x 3.4 = corrected estimate, see Laake et al. 1997). As revealed by the analysis of harbor porpoise sighting rates (Table 1), the density was lowest in the Strait of Georgia. Despite the large size of this region (more than double any other region), it contributed less than 1,000 animals (corrected abundance) to this total. Calculated densities in the other regions were fairly similar and contributions to abundance were generally proportional to their areas.

Dall's Porpoise

Sightings and Geographic Distribution

A total of 97 sightings of 173 Dall's porpoise were made during the surveys, with 76 of these made on-effort (Figure 7). Group sizes of Dall's porpoise ranged form one to five animals, with 87% of the sightings consisting of one or two animals. Dall's were sighted in all regions except the Strait of Georgia.

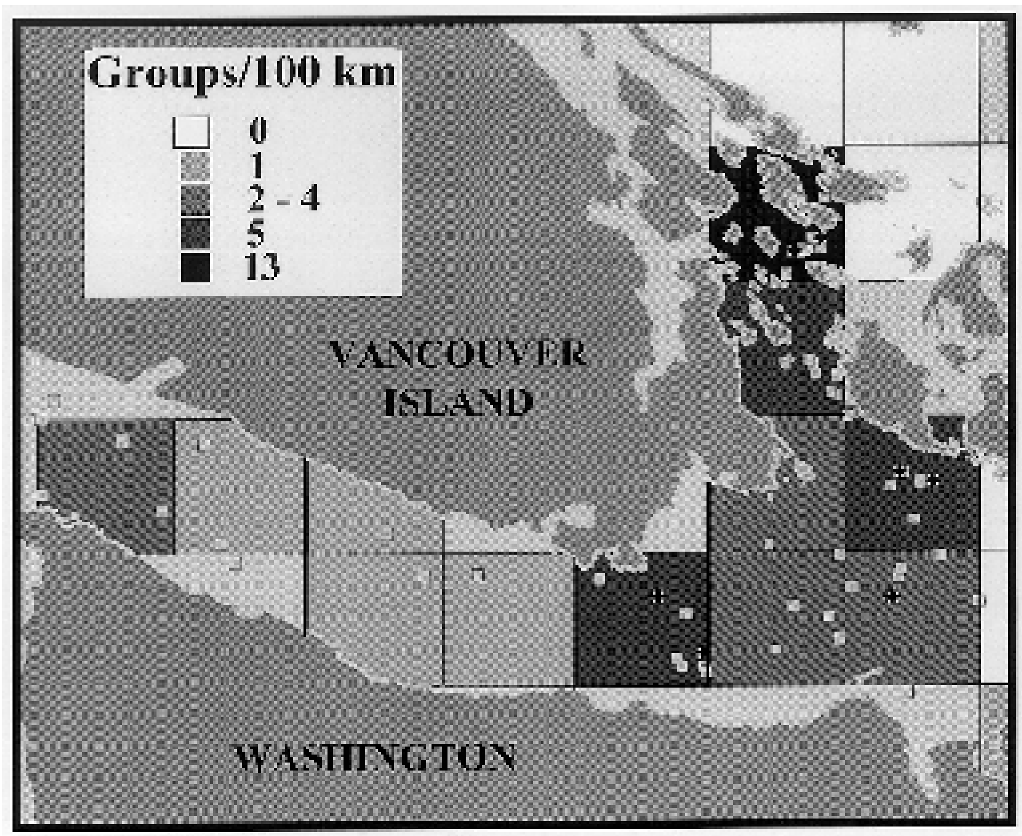

Figure 7. Dall's porpoise and calves (black cross) sighted while on-effort under acceptable visibility conditions. Effort-corrected sighting-rate blocks measured 352 km^2 and contained a minimum of 40 km of aerial effort. No Dall's porpoise were sighted in the Strait of Georgia.

Dall's porpoise were more clumped in their distribution than either harbor seals or harbor porpoise. The overall distribution of group sightings shows few sightings occurring east of Haro Strait and the waters immediately west of Whidbey Island in the eastern Strait of Juan de Fuca. Sighting rates in the regions where Dall's occurred varied little within the Gulf Islands, and were higher (2.2 groups/100 km) than in the Canadian Straits (1.4 groups/100 km). With the Strait of Georgia excluded, (because of the lack of sightings), there were no differences in sighting rate by region. Dall's porpoise were distributed unevenly by depth, with significantly more sightings in the deepest waters (P<0.001) (Figure 5).

Almost one-third of the geographic cells had zero sighting rates (Figure 7). Dall's porpoise sighting rates in the remaining cells ranged from 1–5 groups/100 km. The exception was for one cell encompassing northern Haro Strait/Boundary Pass and the Canadian Gulf Islands, which was dramatically higher (13 porpoise/100 km). This relatively high rate was the result of 11 Dall's porpoise groups being sighted over several minutes during a single replicate survey.

Preliminary Abundance Estimates

The preliminary uncorrected estimate of abundance of Dall's porpoise for all regions for 1996 was approximately 450 animals, with about 60% and 40% of the population found in the Strait of Juan de Fuca and the San Juan/Gulf Island regions, respectively. No correction factor for animals missed on the transect line is available for Dall's porpoise. Because of the similarity between Dall's and harbor porpoise in body size, group composition, and breath rate, we assume, for this study, that the proportion of Dall's porpoise missed is likely similar to that calculated for harbor porpoise (Laake et al. 1997). With this correction factor, the estimated abundance of Dall's porpoise would be about 1,500 for all four regions combined.

Discussion

Regional Differences

It is suspected that the summer distribution of marine mammals in the study area is affected largely by prey availability, especially for those smaller species with high energetic demands (Morejohn 1979). The trans-boundary waters of the San Juan/ Gulf Island regions, which had the highest sighting rates of all three species with respect to both region and the 352 km^2 cells, are unique from the other waters of the study area in ways that may affect prey abundance and distribution. The channel forming Haro Strait has comparable depths to the western Strait of Juan de Fuca (>300 m), even though it divides the two shallowest regions in the study area (NOAA Nautical Chart). Currents in this area and the adjacent waters around Boundary Passage are relatively strong and can exceed several knots (NOAA Tidal Current Tables 1995). Along with these strong currents are distinct tide rips, zones of mixing which were more consistent and prominent there than the other regions we sampled (SDO, personal observation).

Shore- and vessel-based studies have associated greater concentrations of marine mammals with tide rips (harbor seals: Suryan 1995; Dall's porpoise: Miller 1989; and harbor porpoise: Everitt 1980; Flaherty and Stark 1982; Raum-Suryan 1995). These authors and Read (1983), who observed harbor porpoise foraging on herring at rips near the surface, believe these aggregations of marine mammals are related to greater prey abundance. Herring, an important prey species for these marine mammals (Cowan 1944; Pike and McAskie 1969; Stroud 1981), especially during summer (Everrit et al. 1980; Gearin et al. 1995), are associated with areas of such mixing because of zooplankton concentrations along these convergence zones (Battle et al. 1936). These higher aggregations of prey and the possible action of current upwellings possibly transporting herring closer to the water's surface may lead to increased foraging efficiency (Watson 1976).

The lack of marine mammal sightings in the Strait of Georgia, other than harbor seals and harbor porpoise, was surprising because this region had nearly the highest amount of acceptable aerial effort. The absence of other marine mammal sightings there may be related to either animals temporarily leaving this region or a general avoidance of this region. Because this is the first study to systematically survey these waters, no marine mammal sighting data is available for comparison with other seasons or years. The lack of Dall's porpoise sightings in the Strait of Georgia is consistent, though, with the findings of Cowan (1944) and Pike and McAskie (1969), who reported that Dall's porpoise were uncommon in this region relative to Johnstone Strait to the north (Jefferson 1987) and the waters of the Gulf/San Juan Islands to the south (Everitt et al. 1980; Calambokidis et al. 1992).

Evaluation of Areas to be Avoided by Fisheries

Although there were significant patterns in the geographic distribution of the three species tested, these patterns may not be dramatic enough to be of great value to management in reducing incidental take levels in gillnet fisheries. Harbor seals and harbor porpoise, the two species incidentally taken most often in the U.S. San Juans, were present in almost all of the geographic cells as well as distance to shore classes. Consequently, significant reductions in takes through regional or habitat closures would be difficult. Instead, these data might better be used by managers for regulating future human activities that potentially could impact marine mammals and habitat quality, especially in those geographic cells where encounter rates were highest.

Abundance Estimates

The surveys in 1996 provide the best estimates of harbor porpoise abundance in the inside waters of Washington and British Columbia due to their greater and better distributed coverage compared to past surveys. This paper also was the first to report abundance estimates of Dall's porpoise for these inside waters. Although the use of the harbor porpoise correction factor (Laake et al. 1997) to correct for the number of Dall's porpoise missed on the aerial trackline is not ideal, it probably provides a reasonable estimate for Dall's porpoise because these two species are similar in body size, travel in small groups, and have fairly short similar dive intervals.

Given the potential risks to harbor porpoise from incidental entanglements and the evidence of their population decline in Puget Sound proper, the preliminary reanalysis of the 1991 survey data (Calambokidis et al. 1992) and comparison with the estimates from this study are encouraging. This comparison indicates that harbor porpoise numbers probably have not declined in the past five years in the U.S./Canadian Strait of Juan de Fuca and the U.S. San Juan Island regions (Calambokidis et al. in press). Multi-year survey data for the other two regions and information on human-caused mortality for all of these inside waters is still needed to adequately assess the effect of these takes on this harbor porpoise population.

Acknowledgments

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